Design of steel and composite bridges
Highway bridges

Joël Raoul

Main selected features

- General presentation and scope of EC3 and EC4 related to steel and composite bridges
- Materials
- Structural analysis
- Cross-section analysis at ULS and SLS
- Treatment of instabilities
- Fatigue

Eurocode 3 : steel structures

applications

- Partie 4.1 – Silos
- Partie 4.2 – tanks
- Partie 4.3 – Pipelines
- Partie 5 – piling
- Partie 2 – bridges
- Partie 7.1 – pylons
- Partie 7.2 – chimneys
- Partie 6 – Cranes

generic rules

Partie 1.1	**General rules**	Partie 1.7	Plated elements loaded transv.
Partie 1.2	fire	Partie 1.8	**joints**
Partie 1.3	sheetings	Partie 1.9	**Fatigue**
Partie 1.4	Stainless steel	Partie 1.10	**Brittle fracture**
Partie 1.5	**Plated elements**	Partie 1.11	cables
Partie 1.6	shells	Partie 1.12	S500 to S690

EN 1994 : composite steel-concrete structures

EN 1994-2 general rules and bridges

➢(self-sufficient)

CONCRETE PART

EN 1992-2

STEEL PART

EN 1993-2

Scope of EN1993-2

All steel bridges (in general with an orthotropic deck) and the steel part of composite bridges

Scope of EN1994-2

Composite bridges

Girder bridges

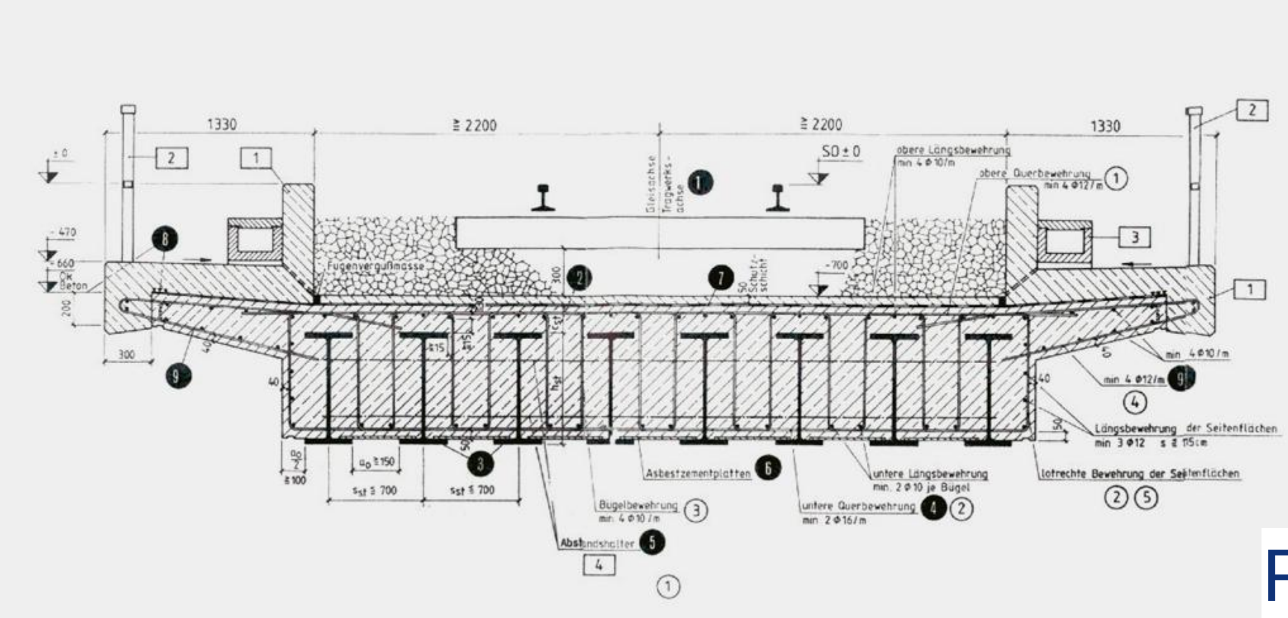
Economy : two-girder bridges even for 2X2 lanes due to robustness rules

Box girders

Composite members

Tension members (tie of bowstring arch)

Composite plates



Filler beam decks

In the transversal direction

In the longitudinal direction

Materials

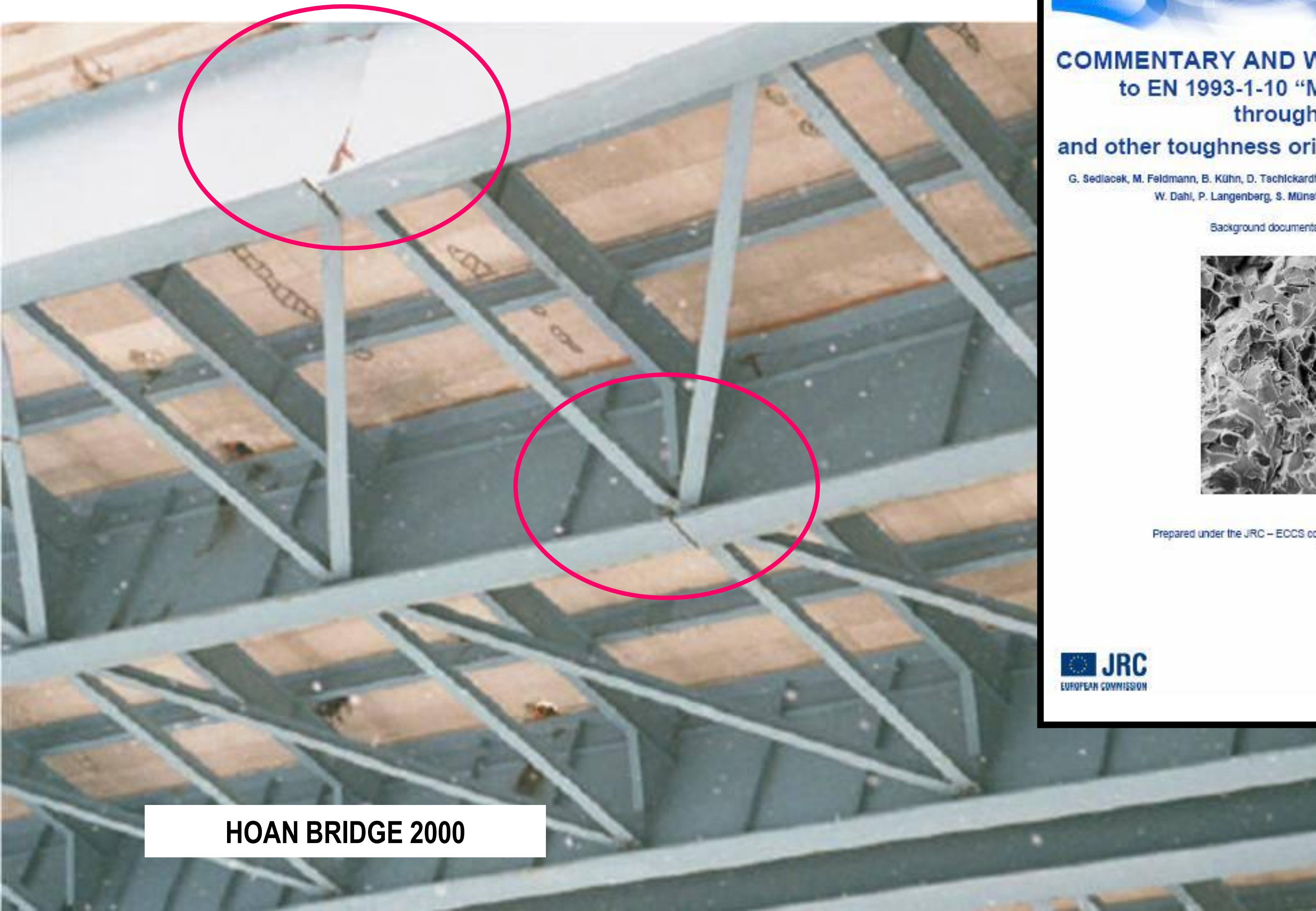
Concrete :

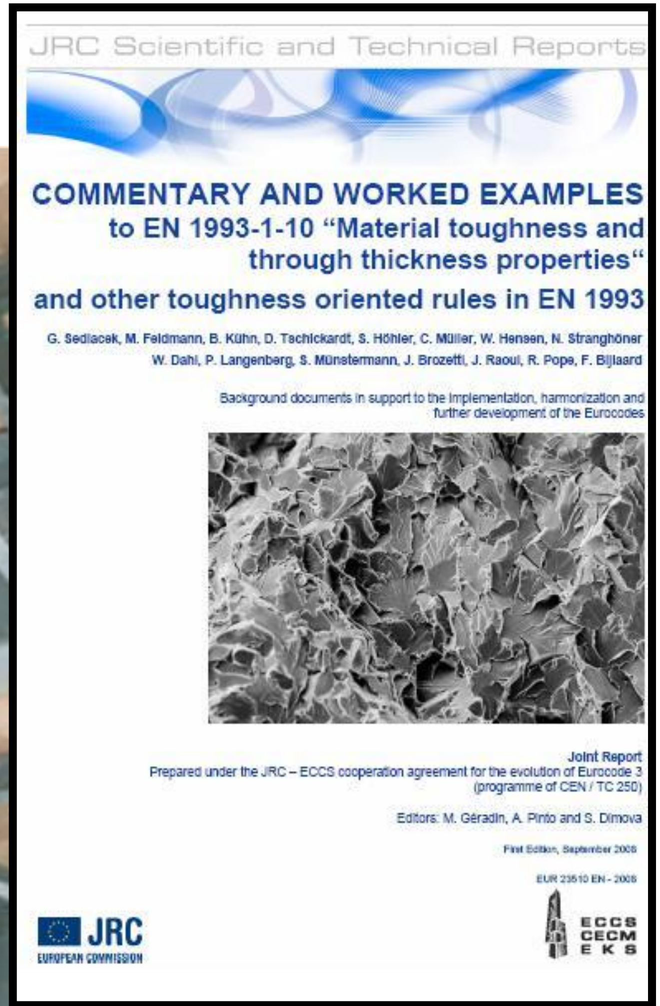
Between C20 and C60 for composite bridges (C 90 for concrete bridges)

Steel :

up to S460 for steel and composite bridges
(S 500 to S 700 in a separate part 1-12 for steel bridges)

Choice of material : avoid brittle behaviour





JRC Scientific and Technical Reports

COMMENTARY AND WORKED EXAMPLES to EN 1993-1-10 “Material toughness and through thickness properties“ and other toughness oriented rules in EN 1993

G. Sedlacek, M. Feldmann, B. Kühn, D. Tschickardt, S. Höhler, C. Müller, W. Hensen, N. Stranghöner, W. Dahl, P. Langenberg, S. Münstermann, J. Brozetti, J. Raoul, R. Pope, F. Bijlaard

Background documents in support to the implementation, harmonization and further development of the Eurocodes

Joint Report
Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 (programme of CEN / TC 250)

Editors: M. Géradin, A. Pinto and S. Dimova

First Edition, September 2008

EUR 23510 EN - 2008

JRC EUROPEAN COMMISSION

ECCS CECM EKS

- An overlooked defect is assumed during execution :
  e.g. : a = 2.2 mm for t_f=80 mm

- It grows acc. to fracture mechanics laws (assuming fatigue is governing the design)

- Up to the critical defect depending on Charpy energy at service temperature

- Over a period depending on the inspection periodicity

NOTE: fabrication rules and quality plan are given in EN 1090 They are assumed to be met when using EN 1993

EN 10025

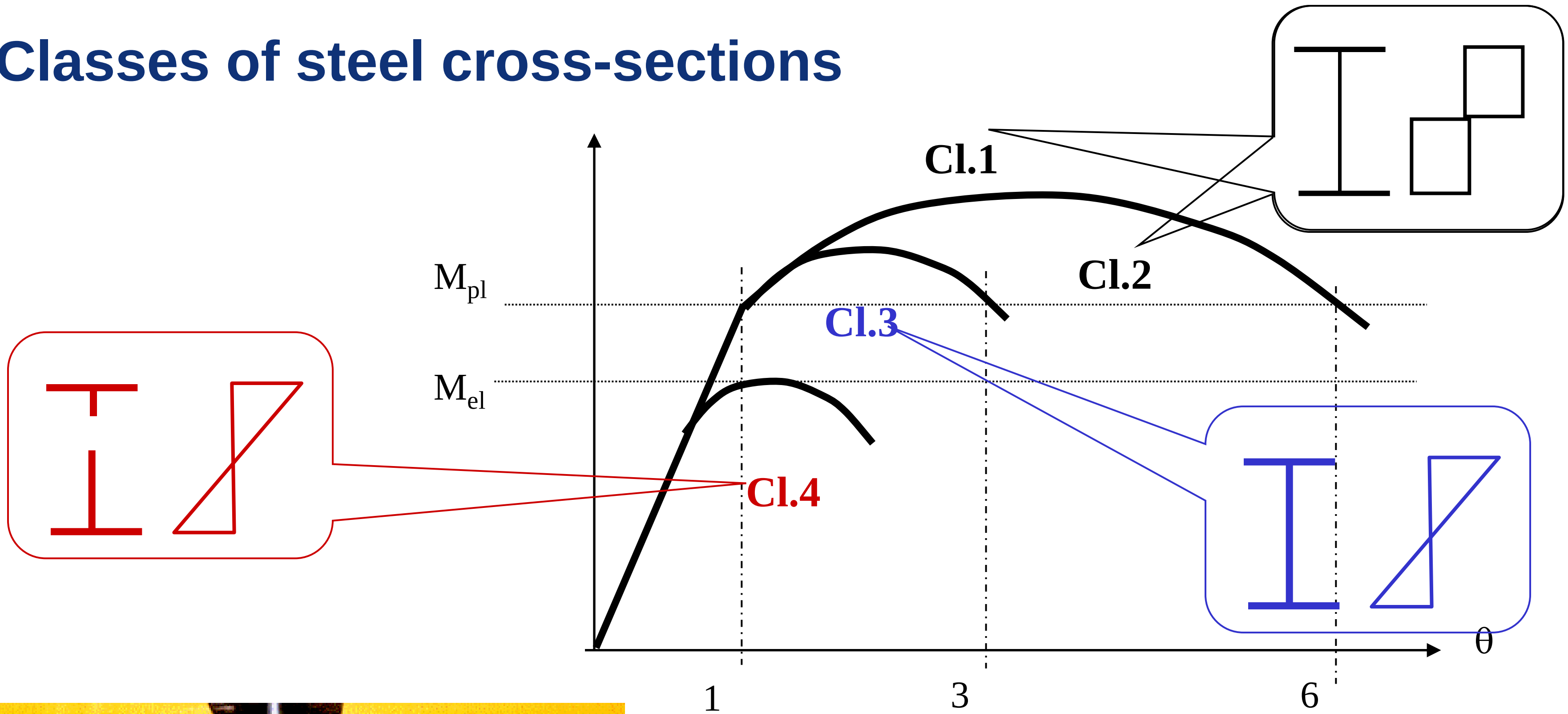
grade	quality	Energie Charpy K_V at T [°C]	J_{min}	Temperature de référence T_{Ed} [°C] 10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0{,}50\ f_y(t)$						
S235	JR	20	27	90	75	65	55	45	40	35
	J0	0	27	125	105	90	75	65	55	45
	J2	-20	27	170	145	125	105	90	75	65
S275	JR	20	27	80	70	55	50	40	35	30
	J0	0	27	115	95	80	70	55	50	40
	J2	-20	27	155	130	115	95	80	70	55
	M,N	-20	40	180	155	130	115	95	80	70
	ML,NL	-50	27	200	200	180	155	130	115	95
S355	JR	20	27	65	55	45	40	30	25	25
	J0	0	27	95	80	65	55	45	40	30
	J2	-20	27	135	110	95	80	65	55	45
	K2,M,N	-20	40	155	135	110	95	80	65	55
	ML,NL	-50	27	200	180	155	135	110	95	80

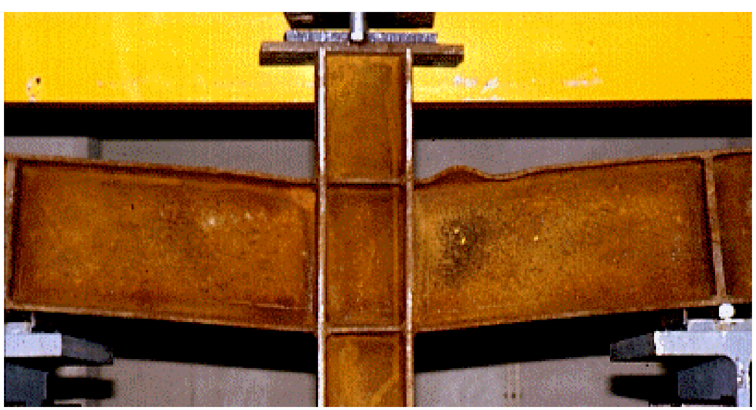
Structural analysis

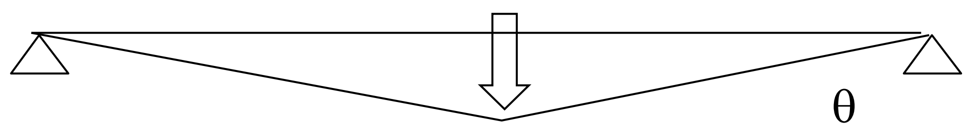
Elastic

Plastic (buildings, bridges in accidental situations)

Classes of steel cross-sections

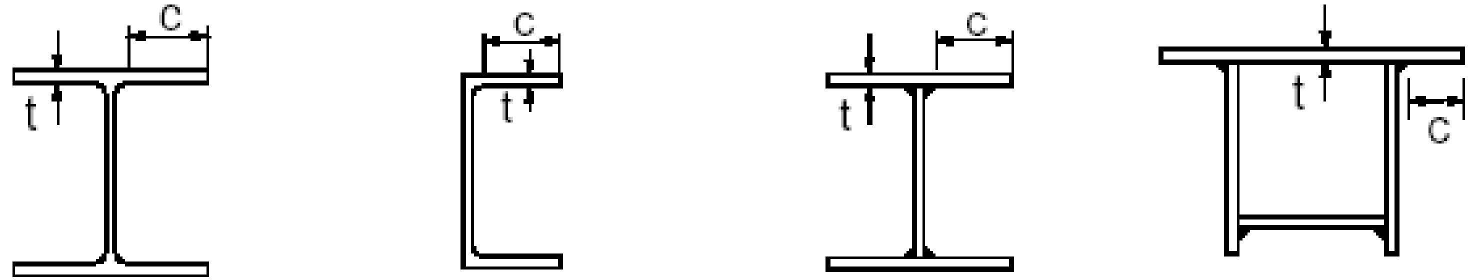




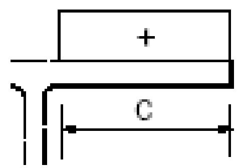
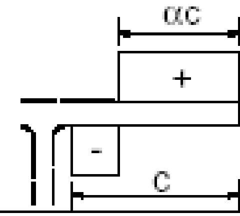
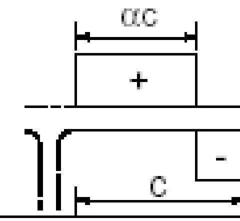
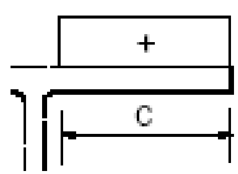
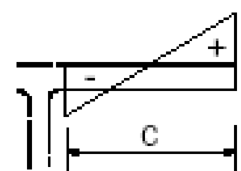
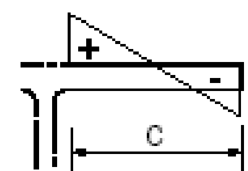


Class of flanges

Outstand flanges

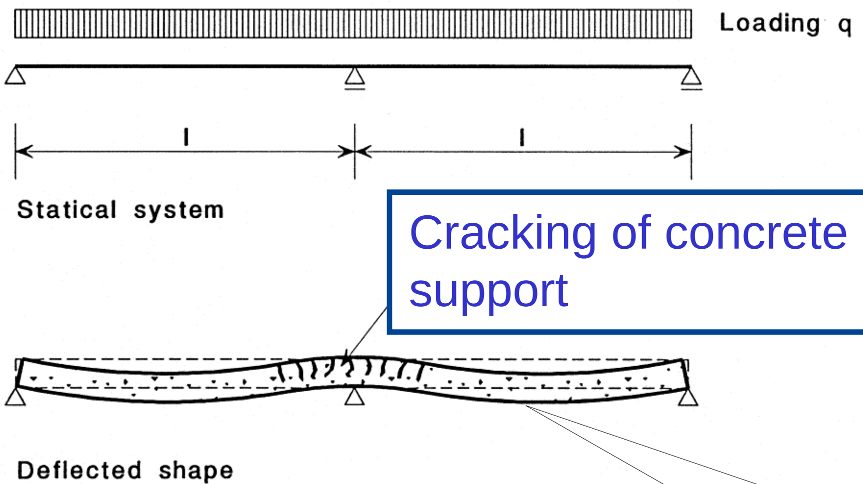


Rolled sections — Welded sections

Class	Part subject to compression	Part subject to bending and compression: Tip in compression	Part subject to bending and compression: Tip in tension
Stress distribution in parts (compression positive)			
1	$c/t \leq 9\varepsilon$	$c/t \leq \frac{9\varepsilon}{\alpha}$	$c/t \leq \frac{9\varepsilon}{\alpha\sqrt{\alpha}}$
2	$c/t \leq 10\varepsilon$	$c/t \leq \frac{10\varepsilon}{\alpha}$	$c/t \leq \frac{10\varepsilon}{\alpha\sqrt{\alpha}}$
Stress distribution in parts (compression positive)			
3	$c/t \leq 14\varepsilon$	$c/t \leq 21\varepsilon\sqrt{k_\sigma}$ For k_σ see EN 1993-1-5	

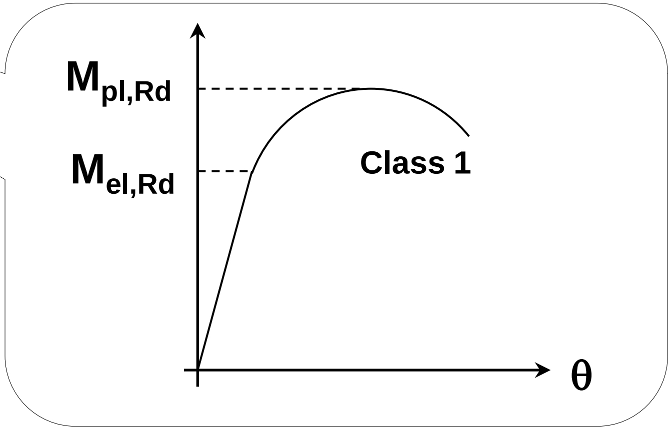
$\varepsilon = \sqrt{235/f_y}$					
f_y	235	275	355	420	460
ε	1,00	0,92	0,81	0,75	0,71

Global analysis of composite bridges: two aspects are considered



Cracking of concrete on support

Non linear behaviour at mid span



Modular ratio used in a composite section

$$n_L = n_0.\left(1+\psi_L \phi_t\right)$$

$n_0 = \dfrac{E_a}{E_{cm}}$ and $\phi_t = \phi\left(t - t_0\right)$ creep coefficient given by EC2 :

Value of t_0 :

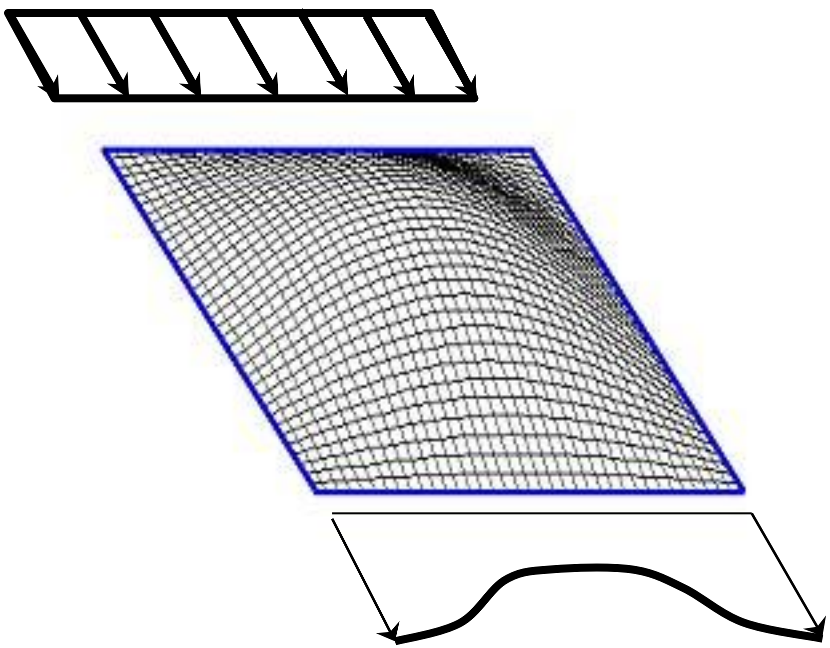
- **t_0 = 1 day for shrinkage**
- **t_0 = a mean value in case of concrete cast in several stages**

SIMPLE CALCULATIONS

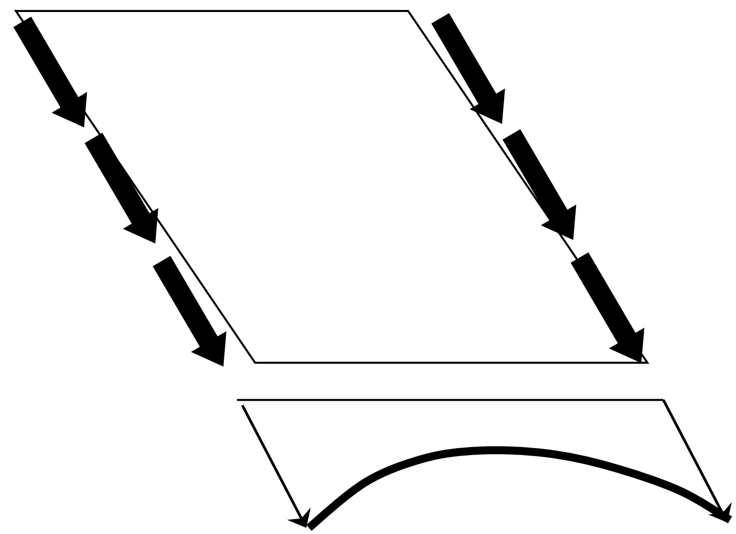
ψ_L is given by :

Permanent loads	1,1
shrinkage	0,55
Imposed deformations	1,5

Plate buckling and shear lag



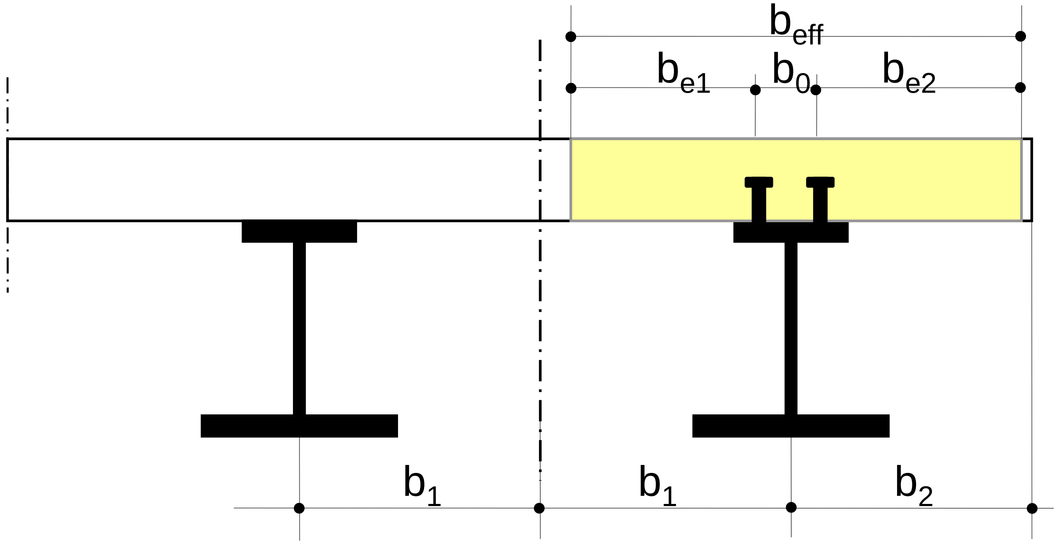
Effective^{p} width
(**p**late buckling)



effective^{s} width
(**s**hear lag)

Effective[s] width of concrete slab (ULS and SLS)

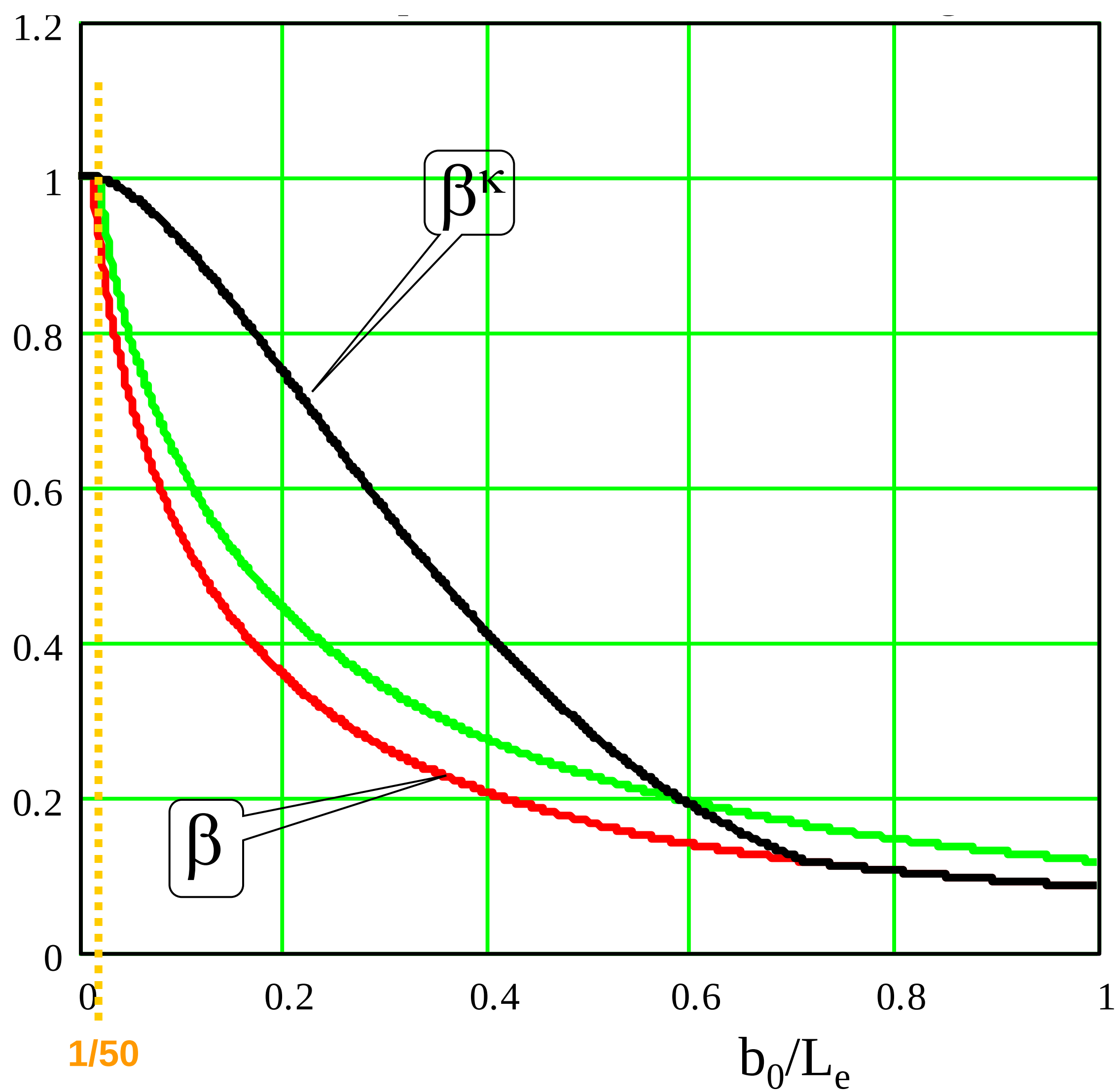
$$b_{ei} = \min\left(\frac{L_e}{8}; b_i\right)$$



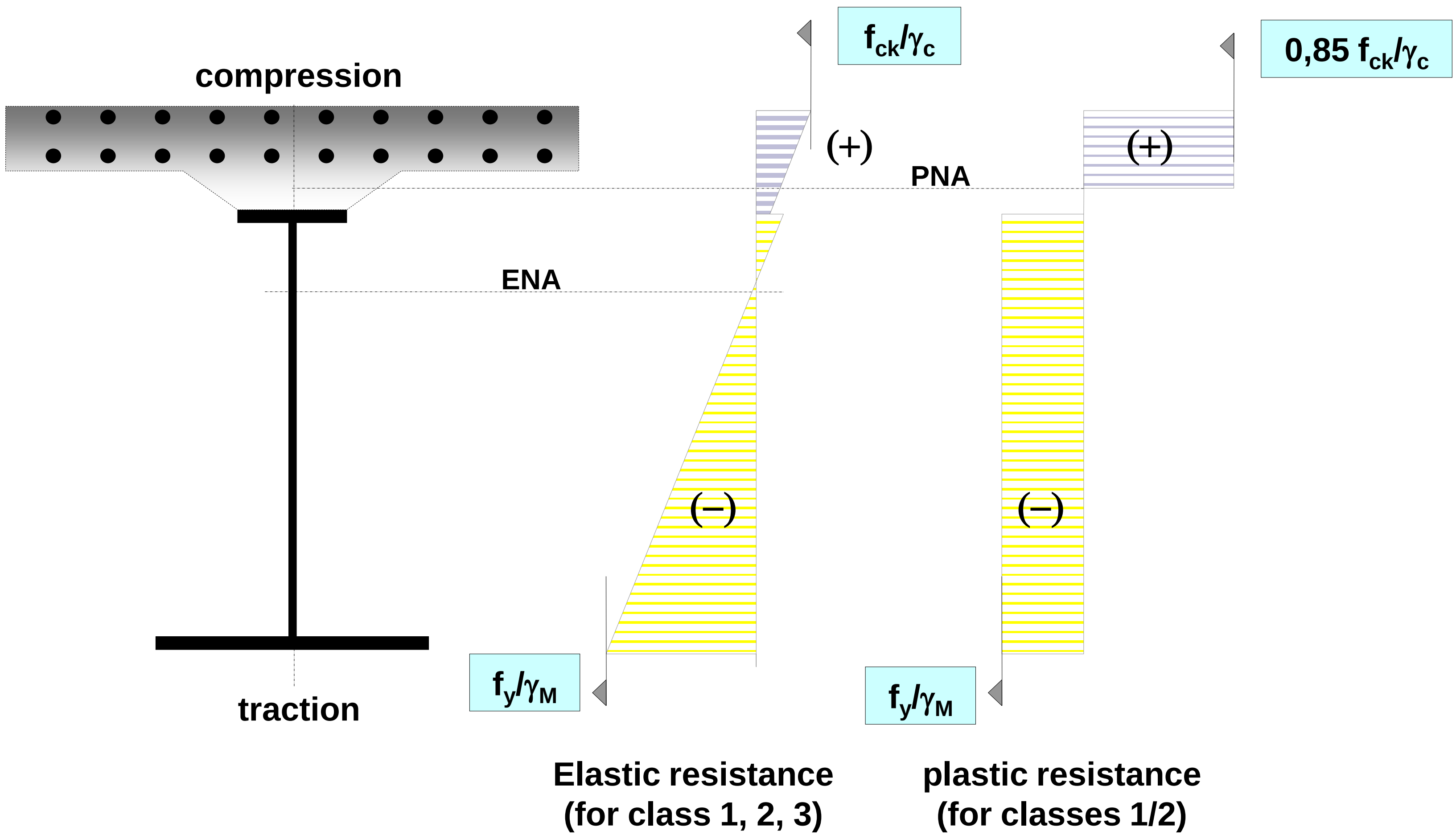
Effectives width of stiffened plates

Shear lag at ULS:
3 alternatives, black one recommended

Shear lag at SLS:
elastic (red line)



Composite cross-section verification at ULS (M>0)



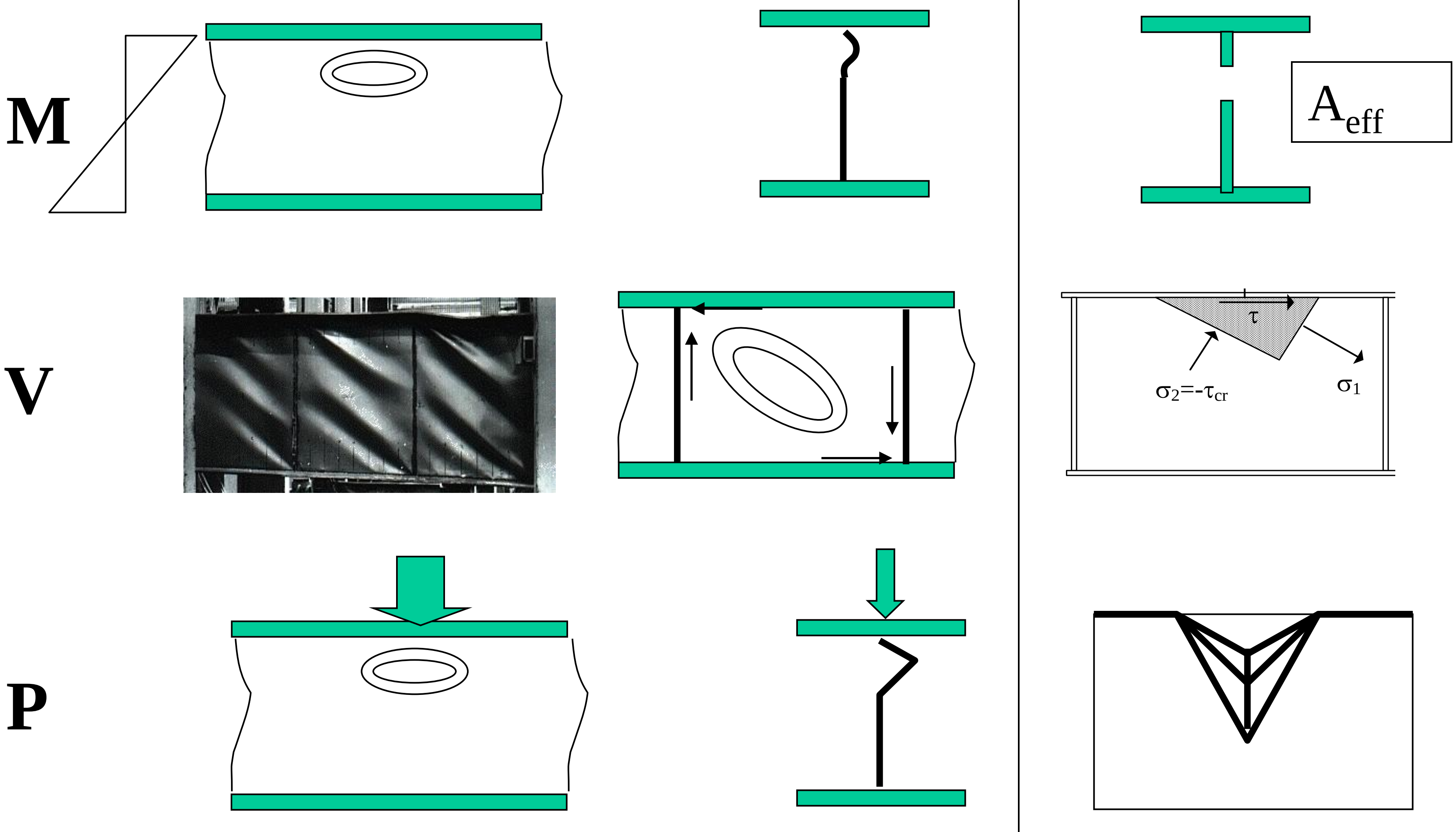
NOTE : γ_M is 1.0 (recommended for resistance formulae)

Verification at SLS

- Limitation of stresses for steel and composite bridges
  - As in EN1992-2 and EN1993-2 (f_y in the steel part)
- Limitation of crack widths for composite bridges
  - As in EN1992-2 with tension stiffening (w_k=0.3mm in general)
  - Using a simplified method

Treatment of instabilities

expérimental behaviour	mechanical model



Principle of verification

α_u = ultimate loading (without instability)/ ULS loading

α_{cr} = critical loading / ULS loading

$$\bar{\lambda} = \sqrt{\frac{\alpha_u}{\alpha_{cr}}} \quad \Rightarrow \quad \chi = f(\bar{\lambda})$$

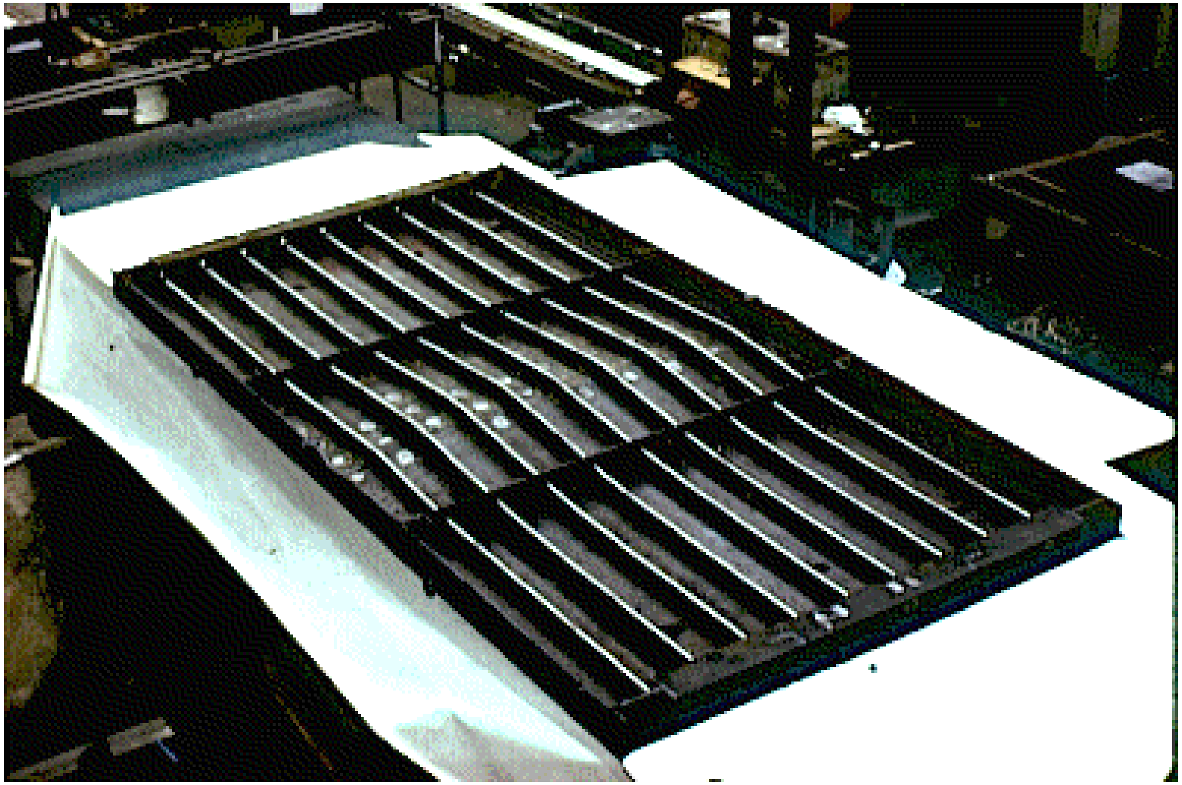
Test /theory (mechanical model) calibration

$$P_{Rk} = \chi P_u$$

$$P_{Rd} = P_{Rk}/\gamma_M$$

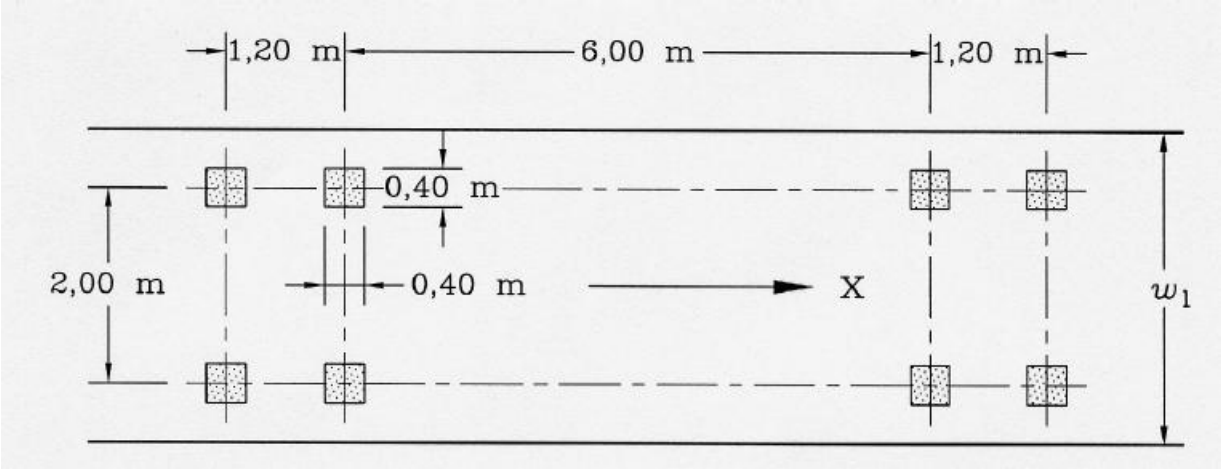
NOTE : γ_M is 1.1 (recommended for « stability » formulae)

Plate buckling of stiffened plates in EC3



Fatigue verification in EC3

Calculation of $\Delta\sigma_{E,2}$ under a fatigue loading



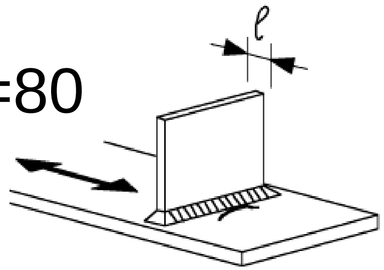
P = 480kN

- Influence of the type of influence line
- Influence of the type of traffic
- Influence of the number of lanes

verification

partial factor for loading= 1,0

$\Delta\sigma_c = 80$

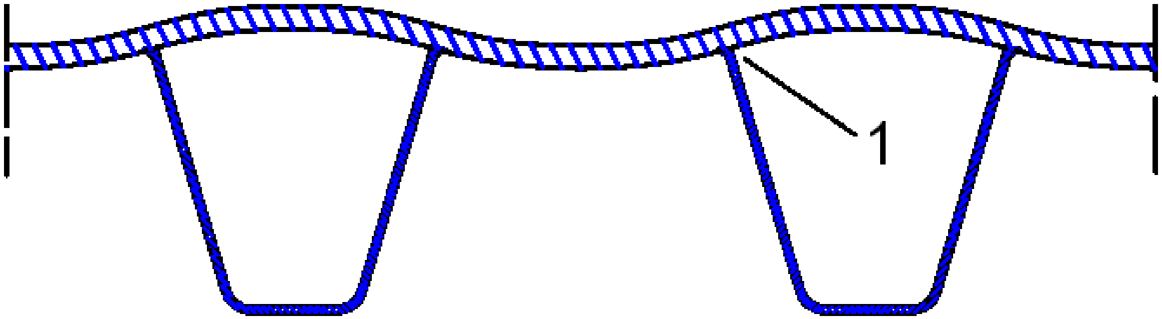


Category of detail

$$\frac{\gamma_{Ff}\,\Delta\sigma_{E,2}}{\Delta\sigma_C / \gamma_{Mf}} \leq 1{,}0$$

Assessment method	Consequence of failure	
	Low consequence	High consequence
Damage tolerant	1,00	1,15
Safe life	1,15	1,35

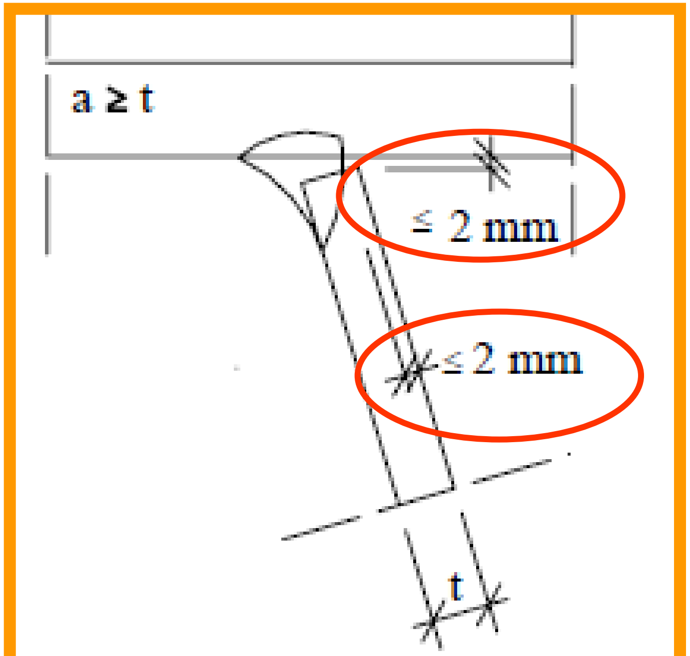
Orthotropic decks : recommended detailing



crack initiation starting at weld root inside the stiffeners

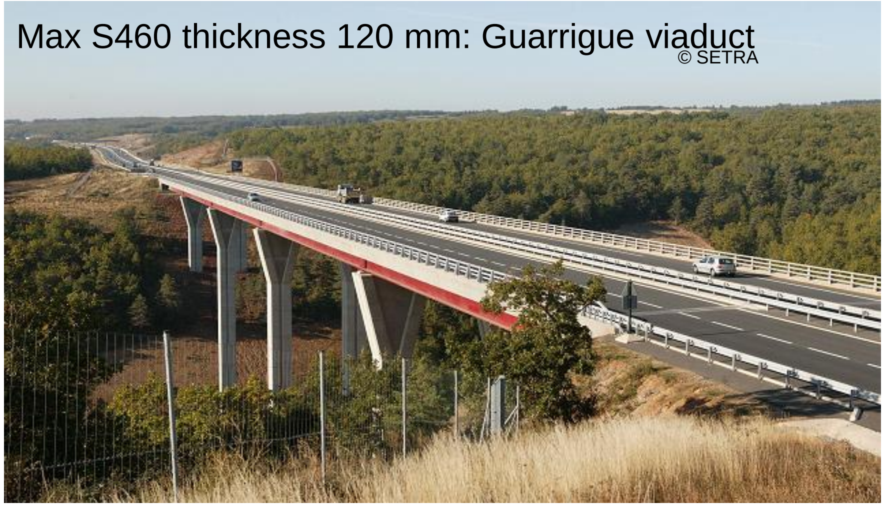
Deck plate thickness in the carriage way in the heavy vehicle lane

t ≥ 14 mm for asphalt layer ≥ 70 mm



1st bridge entirely designed to EC4 in Avignon
4500 t

Outstanding composite bridges



SOME INNOVATIONS / ECONOMY ISSUES

- Enormous scientific work
- Simplicity of calculations
- Robustness (fatigue + brittle fracture)
- Full exploitation of the materials (postcritical range)
- Steels up to S690
- Hybrid girders
- Harmonization of the format and the reliability of all the instability formulae
- Treatment of stiffened plates
- Design of orthotropic decks